Basin Introduction :.

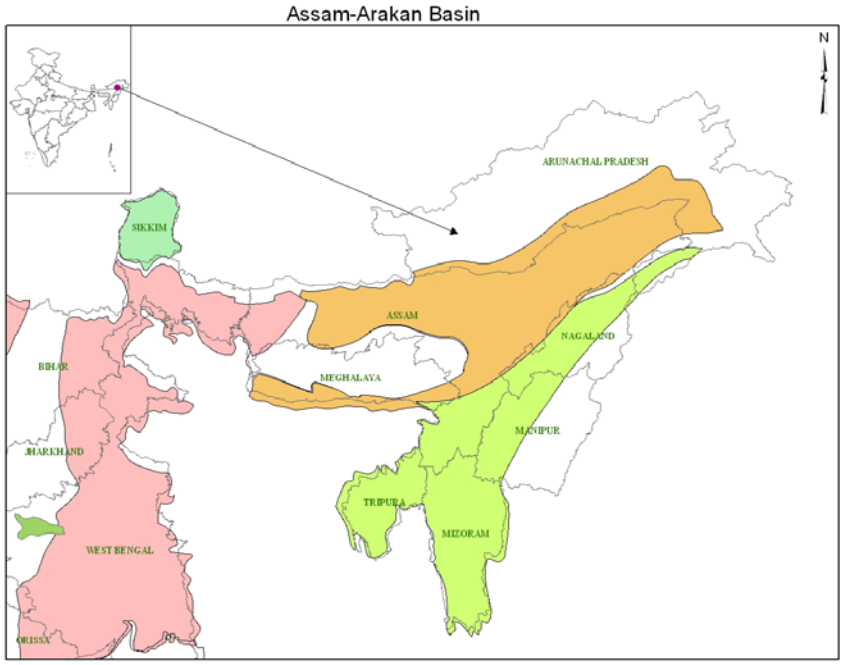
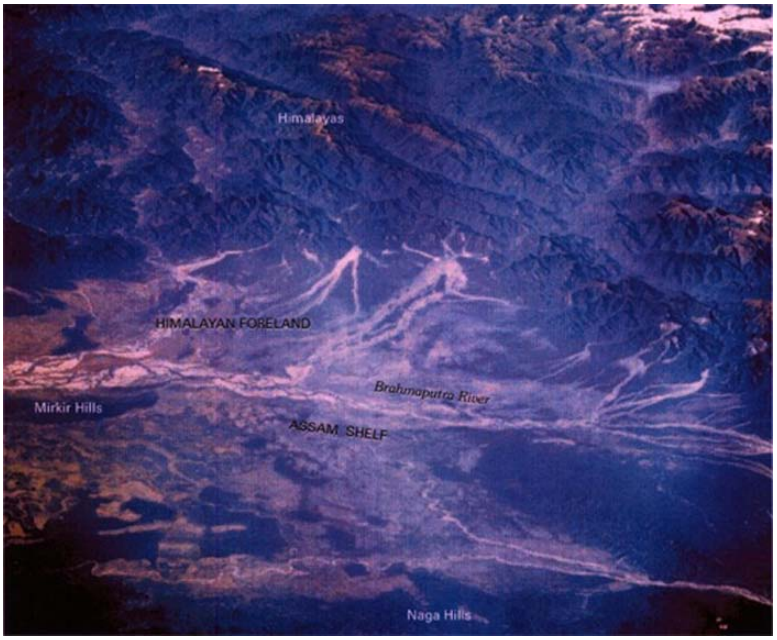


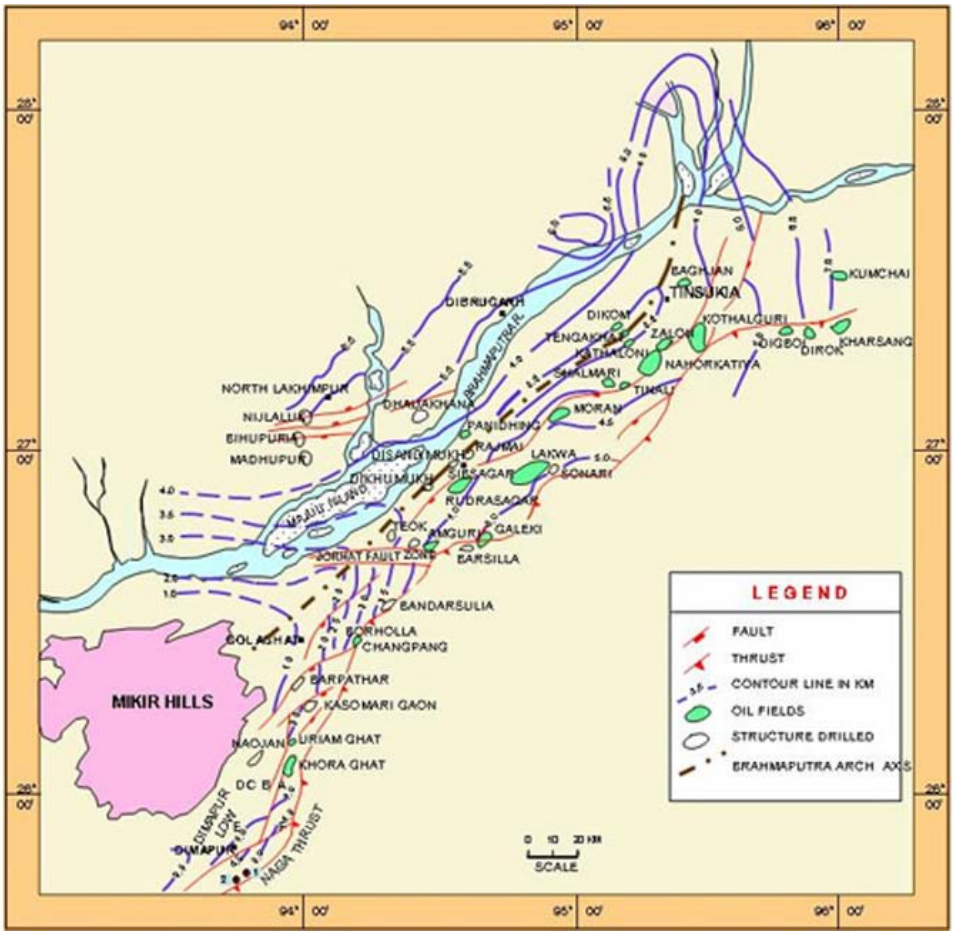
Fig. *Assam-Arakan Basin*

The Assam-Arakan Basin is situated in the northeastern part of India categorized as category-I basin. The basin covers an area of 116000 Sq.Km. Major tectonic elements of the basin are:

- Assam Shelf
- Naga Schuppen belt
- Assam-Arakan Fold belt.



Oil exploration in India commenced with the discovery of the Digboi oilfield in Upper Assam more than 100 years ago, when, based on surface oil shows, a well was drilled on an exposed anticline, associated with the Naga thrust. Other significant milestones in oil exploration in Upper Assam were the discoveries of the Nahorkatiya, Moran and Rudrasagar oil fields in 1953, 1956 and 1960, respectively. Subsequently, more than 100 oil and gas fields, including Jorajan, Kumchai, Hapjan, Shalmari, Lakwa, Lakhmani, Geleki, Amguri, Charali, Borholla, Khoraghat, Baghjan, Dirok etc. have been discovered.



Bulk of the oil and gas, discovered in Upper Assam till late 1980s, has been found in the Barail Group of Upper Eocene to Lower Oligocene age and the Tipam Group of Upper Miocene age. During the last decade, oil and gas accumulations have been discovered within the Langpar and Lakadong formations of Paleocene to Lower Eocene age in several structures like Dikom, Kathaloni, Tengakhat, Tamulikhat, Shalmari, Baghjan, Panidihing, etc. In the Borholla oil field, oil occurs in fractured granitic basement rock of Precambrian age. The oilfields, discovered so far, are situated mainly in the areas south and southeast of the Brahmaputra river and a few in the thrust belts, associated with Naga-Patkai hills. However, the area to the north of the Brahmaputra river up to the Eastern Himalayan foothills has remained poorly explored. In the Naga Schuppen zone, apart from the Digboi oil field, two more

major oil fields, namely, the Kharsang field, having oil accumulations in Upper Miocene to Pliocene reservoirs and the Champang field, having oil accumulations in fractured granitic basement rock of Precambrian age, have been discovered.

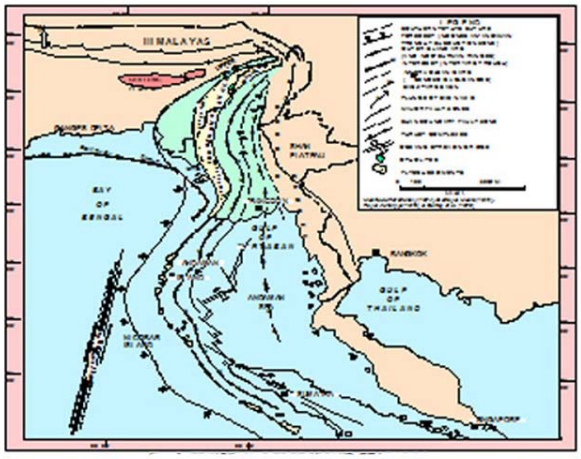
In the Khoraghat and Nambar fields situated in southeastern part of the Dhansiri Valley, oil occurs in the Bokabil Formation (Middle Miocene) which is not developed towards north in the Brahmaputra valley. In some of the exploratory wells, drilled in the southwestern part of the Dhansiri valley, good shows of oil have been observed in Eocene and Oligocene sands.

Tectonic History :.

The Assam-Arakan sedimentary Basin is a shelf–slope–basinal system. The shelf part of the basin spreads over the Brahmaputra valley and the Dhansiri valley, the latter lying between the Mikir hills and the Naga foothills. From the Digboi, the shelf runs westward to the southern slope of the Shillong plateau. The shelf-to-basinal slope, i.e., the hinge zone lies below the Naga schuppen belt. The basinal (geosynclinal) part is occupied by the Cachar, Tripura, Mizoram and Manipur fold belts.

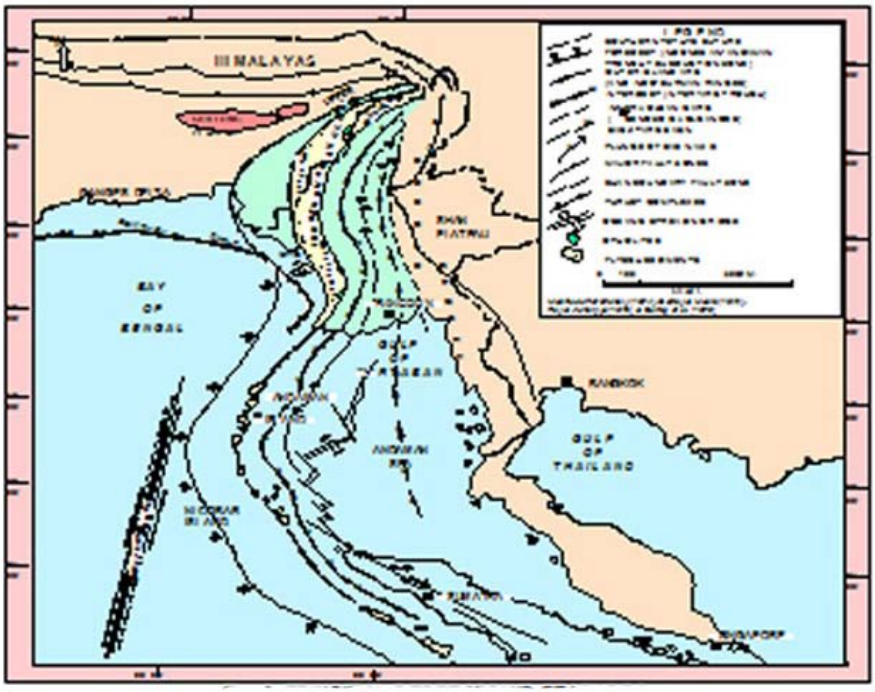
The shelf part rests on Precambrian granitic basement, whereas the basinal part lies on transitional to oceanic crust. The area within the Upper Assam shelf, having high petroleum potential, measures approximately 56000 sq km and contains about 7000m thick sediments of mostly Tertiary period, and the area in the basinal part with moderate to high hydrocarbon potential measures about 60,000 sq km and contains more than 10,000m thick sediments of mostly Tertiary period.

The major structural elements of the Assam–Arakan Basin and the salient features of each element are briefly described as following.



Upper Assam Shelf

1. Southerly to southeasterly moving thrust sheets of younger (Miocene to Plio-Pleistocene) sedimentary rocks in the Assam Himalayan foothills.
2. The Himalayan Foredeep zone north of the Brahmaputra river lies in the northern periphery of the foredeep is overridden by the southerly moving thrust sheets of younger sedimentary rocks.
3. The Brahmaputra-Arch, running along the southeastern side of the Brahmaputra river in Upper Assam.



4. The southeastern slope of the Upper Assam Shelf, southeast of the Brahmaputra arch, having local structural highs and lows, upto the Naga thrust, and extending 8 to 10 km beneath the Naga schuppen belt . This element contains most of the oil fields of the Upper Assam Shelf.
5. The Shillong Plateau and Mikir hills Uplift, composed mostly of Precambrian granitic and metamorphic rocks. The southern slope of the Shillong Plateau exposes Gondwana, Cretaceous and Tertiary rocks.

Shelf–To–Basinal Slope To Basinal Area

1. **The Naga Schuppen Zone,**occurring between the Naga and the Disang thrusts. In this shelf–slope–basinal architecture, the hinge zone, at and across which the Upper Cretaceous-Eocene shelf facies changes over to basinal facies, is envisaged to lie below the Naga schuppen belt. The Kharsang, Digboi and Champang oil fields are located in this element.

2. **The Assam – Arakan Fold Belt** This fold belt may be divided into two zones bounded by prominent thrusts, viz, (i) the Naga fold zone, lying in between the Disang and Tapu thrusts and having exposures of Disang shales and Barail sediments, and (ii) the central flysch zone, lying between the Tapu thrust and Changrang – Zunki thrust and having exposures of mainly Disang shales.
3. **The Zunki schuppen belt,** containing mostly older Disang shales (Upper Cretaceous) & occurring between the Zunki and Moya thrusts.
4. **The Ophiolite Complex,** occurring in between the Moya and the Eastern thrust. Disang shales, occurring in association with ophiolites, are somewhat metamorphosed here.
5. **The Naga Metamorphic Complex,** east of the Eastern thrust. The metamorphic complex occurs mostly to the east of the Indo-Myanmar international border.

Stratigraphy :.

Sedimentary sequences ranging in age from Late Mesozoic to Cenozoic are exposed in the Assam-Arakan Basin. The sequences can be divided into shelf facies and basinal (geosynclinal) facies. The shelf facies occur in Garo hills, Khasi-Jaintia hills, parts of North Cachar hills and Mikir hills, and below the alluvial cover in Upper Assam, Bengal and Bangladesh. The basinal facies occur in the Patkai range, Naga Hills, parts of North Cachar hills, Manipur, Surma valley, Tripura, Chittagong hills of Bangladesh and Chin hills of Myanmar (Burma).

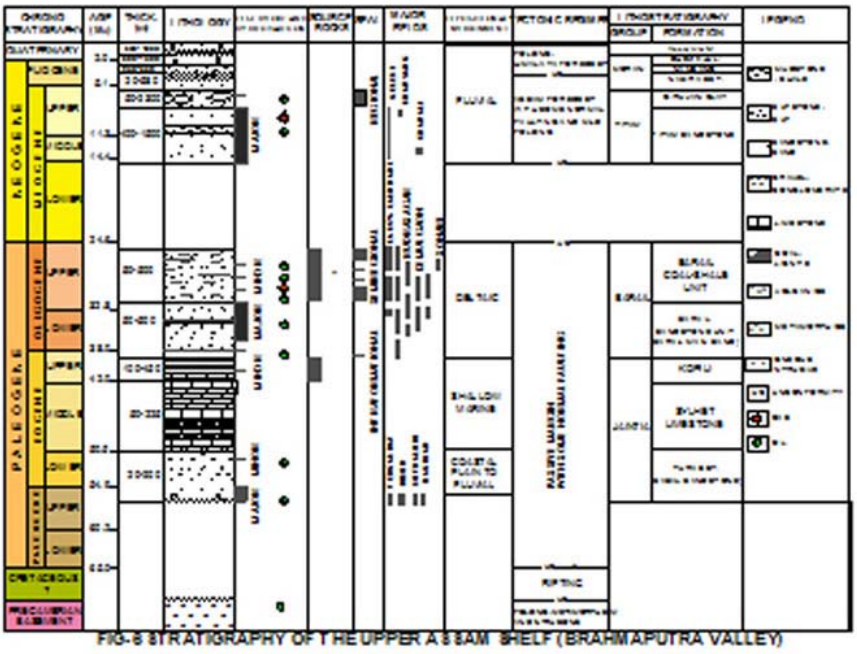


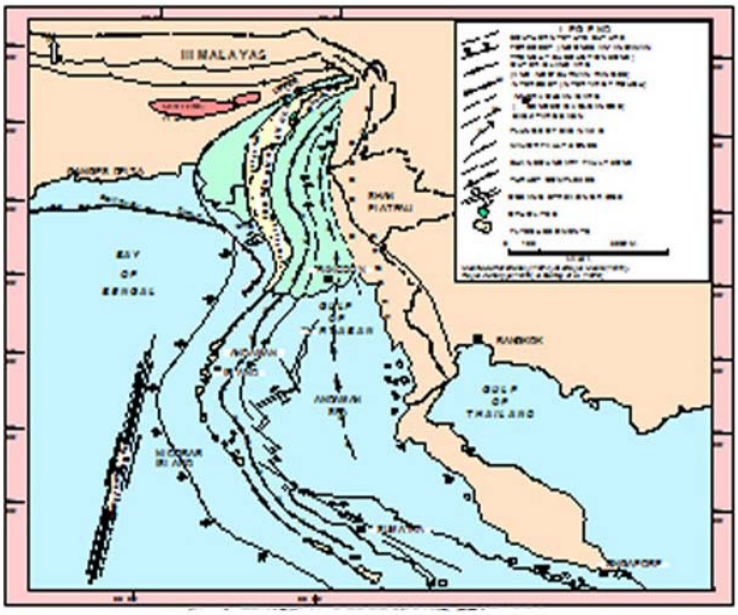
Fig. *The generalized stratigraphic succession.*

Geological History

The Assam-Arakan basin witnessed two major phases of tectonic development. It developed as a composite shelf-slope-basinal system under a passive margin setup during the period from Early Cretaceous to the close of Oligocene. During the post-Oligocene time, however, different parts of the mega basin witnessed different evolutionary trends, mostly under compressive tectonic forces.

During Middle to Late Cretaceous, when the Indian plate was moving northward, a number of horst and graben features developed on the granitic crust in the southern slope of the Shillong Plateau and Dhansiri valley. In these grabens, a sequence of sandstones, shales and subordinate limestone towards top, assigned to the Khasi Group, was deposited in the southern slope of the Shillong Plateau, and a sequence of sandstone and shale, assigned to the Dergaon Group, was deposited in the Dhansiri valley. Presence of pelagic fauna indicates that these sediments were deposited in shallow shelf to open marine conditions during Maestrichtian to Early Paleocene time. During this time, the basinal area to the east and southeast witnessed deposition of Lower Disang shales, radiolarian cherts and subordinate limestones in the distal deeper part of a marginal downwarp, i.e., tilted broad shelf adjacent to ocean basin. The limestones with negligible impurities were, perhaps, deposited on sea mounds.

The Indo-Burmese trench system that developed during the oblique subduction of the Indian plate below the Burmese plate became the locus of deposition of Upper Disang shales under deep marine conditions. The formation of the trench system was, possibly, initiated in the northeastern part and gradually progressed southward. The closing of the trench system was also initiated in the northeast and then gradually progressed southward. The Andaman trench, which has been receiving mostly argillaceous sediments since, possibly, Upper Cretaceous-Paleocene, is the southward extension of the Indo – Burmese trench system.



During Paleocene, there was a marine transgression on the southern edge of the Shillong Plateau, depositing sediments of the Therria Formation consisting of limestone, sandstone and shale. The Lakadang Formation (Early Eocene) comprising limestone and coal bearing sandstones was deposited in shallow marine to lagoonal conditions, while the overlying Tura Sandstone Formation (Early Eocene) was deposited under fluvio-deltaic environment. The Tura Formation is extensively developed in the Upper Assam Shelf and is oil bearing in Borholla, Champang and Nahorkatiya oil fields.

During Eocene to Oligocene, due to the rise of the peripheral arc system (rise of the basement ridge) consequent upon the active oblique subduction of the Indian plate, the intervening sea became progressively narrower southward. During this period, the Assam Shelf was being evolved in a passive margin tectonic setting and under shallow marine to brackish water sedimentation conditions.

Following the deposition of the Tura Sandstone, there was a wide spread marine transgression in which the Sylhet Limestone (Middle Eocene) was deposited almost all over the Upper Assam Shelf. Towards the close of Middle Eocene, limestone deposition ceased because of an increase in the influx of finer clastics in the shelf. These clastics, making the lower part of the Kopili Formation, were deposited in open marine conditions during Late Eocene, when marine transgression was waning out. Further increase in the clastic influx in the stable shelf during Late Eocene to Early Oligocene resulted in marine regression with the deposition of the upper part of the Kopili Formation, consisting of shales, siltstone and subordinate sandstones, in shallow marine to pro-delta environments. In the North Bank of the Brahmaputra river, however, environmental conditions were deltaic with the deposition of sandstones with minor shales and siltstones.

East of the hinge zone, i.e., in the basinal area, Upper Disang shales, which are lateral facies equivalent of the Sylhet and Kopili formations, were deposited in deep water basinal conditions. During shallowing of the sea in the basinal area, the succeeding sediments of the Barail Group were deposited under environments ranging from moderately deep marine to deltaic.

Following completion of collision and subduction of the oceanic part of the Indian plate during Late Oligocene (to Early Miocene?) when the continental part of the Indian plate seems to have come close to Tibetan and Myanmar (Burmese) plates, there was upliftment and erosion all over the shelf and in a major part of the basinal area. This event was followed by a pronounced south to southeastward tilt of the basin, mostly the geosynclinal part, which was, perhaps, caused by subduction related tectonic loading. This foredeep was the site of deposition of the Surma Group of sediments under shallow marine (lower part) to brackish water (upper part)

environments. Continued indentation by the Indian plate caused westward propagation of tectonic forces, which in turn caused development of a decollement thrust at the base of the Upper Disang shales, and a number of synthetic thrust faults. These lateral tectonic movements were accompanied by upliftment and total withdrawal of the sea, heralding the onset of continental sedimentation (the Tipam Sandstone Formation) on the Assam Shelf as well as on the earlier basinal area. Presence of radiolarian chert and ophiolite fragments in the lower part of the Tipam Sandstone in many of the Dhansiri Valley and Upper Assam wells suggest that a certain fraction of the sediments making the lower part of the Tipam Formation came from the rising Barail Range towards east (Barail sediments in the Barail Range are reported to contain volcanogenic particles) or from the Ophiolite belt.

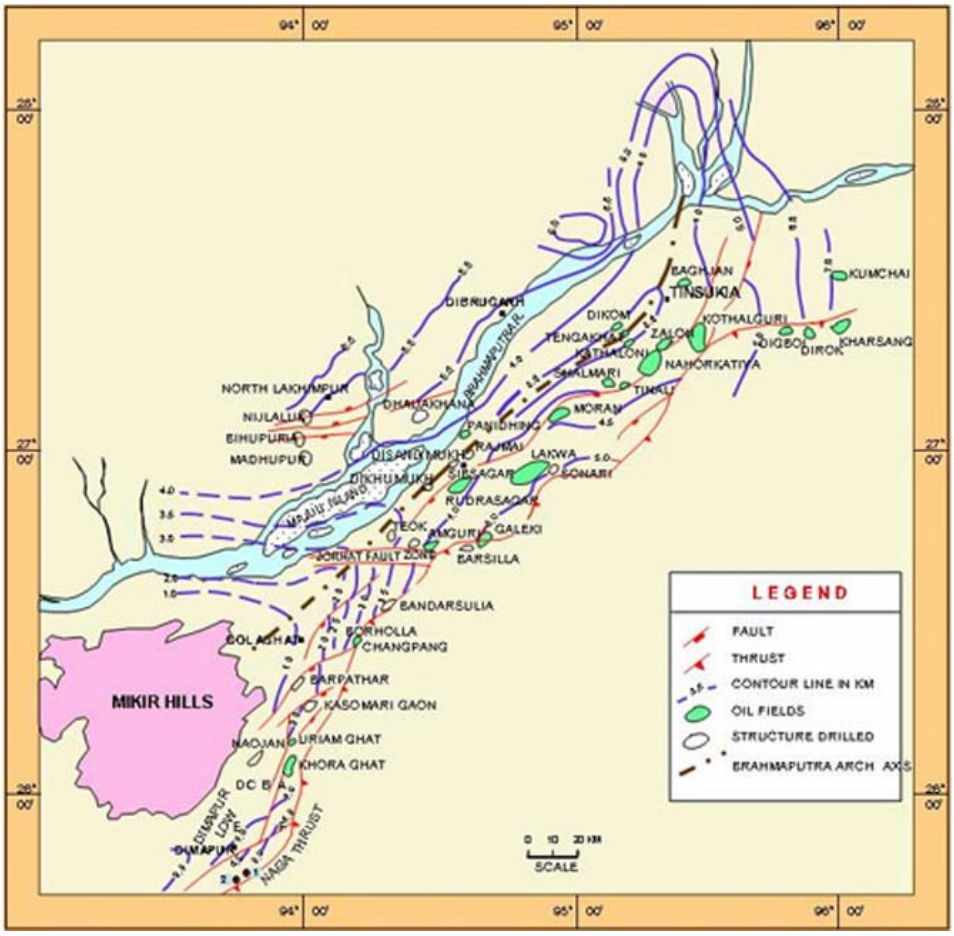
Towards the end of the Tipam Sandstone deposition, there developed a series of N-S to NE-SW trending compressive structures in the basinal area. During the growth of these structures, the Girujan Clay Formation was deposited in the synclinal lows (structural basins) in Cachar area as indicated by seismic and well data from the Katakhal syncline of Cachar area where the Girujan Clay Formation is named as the Govindpur Formation. The Girujan Formation in the eastern & northeastern parts of the shelf also was deposited in structural lows. The most prominent structural depression was formed in Kumchai – Manabhum area in front of the Mishmi uplift, where the Girujan Clay Formation attains a thickness of about 2300m.

The development of the frontal foredeep in front of the rising Himalaya, during Mio-Pliocene and later times, due to tectonic loading by thrust slices was filled with coarser sediments. During this time, sedimentation in the Surma basin (including Sylhet trough) and the Kohima synclinorium took place in intermontane basins, depositing the arenaceous Lower Dupitila sediments over a post–Girujan unconformity and the argillaceous Upper Dupitilas over a post-Lower Dupitila unconformity. During Pleistocene time, there was the last major folding movement and further upliftment of the Barail Range, the Central Disang uplift, the Mishmi Hills and the Himalaya. The Dihing boulder conglomerates, shed by the rising mountains were deposited at the feet/toes of the rising mountains. The Dhekiajuli Formation, consisting of mostly soft sandstones, was deposited at the mountain fronts in the Upper Assam Shelf and in areas now overridden by younger Naga thrust.

Petroleum System :.

All the oil and gas fields, discovered till date in the Upper Assam shelf, are situated mostly on the southeastern slope of the Brahmaputra arch, and almost all the major oil fields like Nahorkatiya, Lakwa, Lakhmani, Geleki, Dikom Kathaloni etc. lie in a belt bordering the Naga thrust. In the Dhansiri valley also, oil fields like the Borholla

and Khoraghat and Nambar lie in the same belt. In the Naga Schuppen belt, oil accumulations in the Lakshmijan and the Champang oil fields occur in that zone of the shelf which is overridden by the Naga thrust. In the Digboi and Kharsang oil fields, oil occurs in Tipam Sandstone and Girujan Clay formations, respectively, overlying the Naga thrust.



Source Rock and Hydrocarbon Generation

The important source rock sequences occur within the argillaceous Kopili Formation and in the Coal-Shale Unit of the Barail Group. The average TOC of shales within the Sylhet Formation is about 0.60%, in the Kopili Formation, about 2.5% and in the Barail Coal-Shale Unit, about 3.8%. The average TOC ranges of different formations (shale samples) are as follows:

Formation	Average TOC Range	Remarks
Barail (shales)	2.5% to 4.5%	Excellent source potential
Kopili (shales)	1% to 3%	Excellent source potential
Sylhet Limestone	~ 0.61%	Poor source potential
Basal Sandstone	~ 0.62%	Poor source potential

Organic matter richness of shales increases towards the Naga thrust. In both Kopilis and Barails, the organic matter is terrestrial type-III with varying contributions of Type-II.

Barail Coal-Shale Unit in the Schuppen belt also form important source rock sequence. In the Naga fold belt, in addition to above, Disang shales also possess excellent source rock characteristics with TOC around 4% and VRo varying from 0.69% to 1.94%.

Geochemical analysis of exposed sediments from the Schuppen belt show a TOC range of 0.64-1.20% for Barail shales. The dominant organic matter type is structured terrestrial. Presence of amorphous (upto 60%) and extractable organic matter (upto 55%) indicates a fairly good liquid hydrocarbon generating potential. Organic matter is mainly humic and sapropelic. TAI of 2.6 to 2.75 and VRo of 0.57 to 0.67% show that the sediments are thermally mature and within oil window. In the subthrust, the source sequences occur at greater depths and, therefore, should be in a higher state of thermal maturity. It is expected that the source sequences within the Kopili and Barail formations in the subthrust would be at the peak oil generating state.

Reservoir Facies

Barring the Borholla and Champang oil fields of the Dhansiri valley and the adjacent schuppen zone respectively, where oil occurs in fractured granitic basement rock (Precambrian) and Tura sandstones (Upper Paleocene/ Lower Eocene), oil in the Upper Assam Shelf and schuppen belt occurs in sandstone reservoirs ranging in age from Upper Paleocene-Lower Eocene to Mio-Pliocene. However, the major accumulations occur in Upper Paleocene + Lower Eocene, Oligocene (Barail Formation) and Miocene (Tipam Sandstone) sandstones. The major oil fields, where oil occurs in Upper Paleocene and Lower Eocene sandstone reservoirs are Tengakhat, Dikom, Kothaloni, Baghjan and in Oligocene sandstone reservoirs (Barail Formation), are Nahorkatiya, Hapjan, Shalmari, Geleki, Lakwa, and Rudrasagar etc. Oil reserves in Kopili sandstones (Upper Eocene) are found mainly in the Geleki field. Most of the oil in the Tipam Sandstone is found in the Lakwa-Lakhmani and Geleki fields. In the Kumchai and Kharsang fields of Arunachal Pradesh, oil occurs in the Girujan Formation of Mio-Pliocene age. Recently gas has been discovered in the sandstone reservoir of Dirok structure within Girujan Formation. The Girujan Clay being floodplain deposits, the reservoir sands are generally lenticular and some what erratic in distribution. In the Khoraghat oil field of Dhansiri valley, oil occurs in sandstone reservoirs within the Bokabil Formation (Middle Miocene). In the North Cachar area of Assam, potential reservoir rocks are expected to be fractured granitic

basement rock (Precambrian)and sandstones in the Tura (Paleocene), Kopili (Upper Eocene), Renji (Oligocene), Bhuban and Bokabil (Middle Miocene) formations.

Cap Rock and Entrapment

There are three well developed regional cap rocks within the Tertiary sedimentary succession, the lower one, occurring in the Upper Eocene is the argillaceous Kopili Formation, the middle one is the Barail Coal-Shale Unit and the upper one, overlying the Tipam Sandstone is the Girujan Clay. Most of the oil accumulations, discovered till date in the Upper Paleocene-Lower Eocene, Oligocene (Barail) and Miocene (Tipam Sandstone) reservoirs, occur in structural combination (fold + fault) traps developed by compressive forces during Mio- Pliocene and later times. Most of these hydrocarbon traps, particularly those developed in post- Barail sediments, orient parallel to the Naga thrust. Faults associated with these traps in the southeasterly sloping shelf zone in the Brahmaputra and Dhansiri valleys have NE-SW to NNE-SSW orientation. Most of the prominent faults continue upward into post-Tipam sediments, and the rest die out in the lower part of the Tipam Formation. Some of the prominent faults, particularly those near the Naga thrust, are reverse faults, e.g., one at the northeastern flank of the Geleki structure, another at the northern flank of the Rudrasagar structure. It may be mentioned that oil, generated in the Kopili and Barail source beds, accumulated in post-Barail sediments by vertical migration through such prominent faults. Oil within the Kopili Formation (composed predominantly of shales with subordinate sandstone) occurs in strati-structural combination traps, as in the Geleki field. Oil within the Girujan Clay Formation as in the Kumchai and Kharsang fields also occurs in combination traps, but here the control of lithology on accumulation is more than that of structure. In the Borholla field of the Dhansiri valley and Champang field of the neighbouring schuppen belt, oil reserves occur in structurally controlled subtle trap in fractured basement rocks. Oil accumulations within the Bokabil Formation (Middle Miocene) in the Khoraghat and Nambar fields of the Dhansiri valley, occur in structural combination traps.

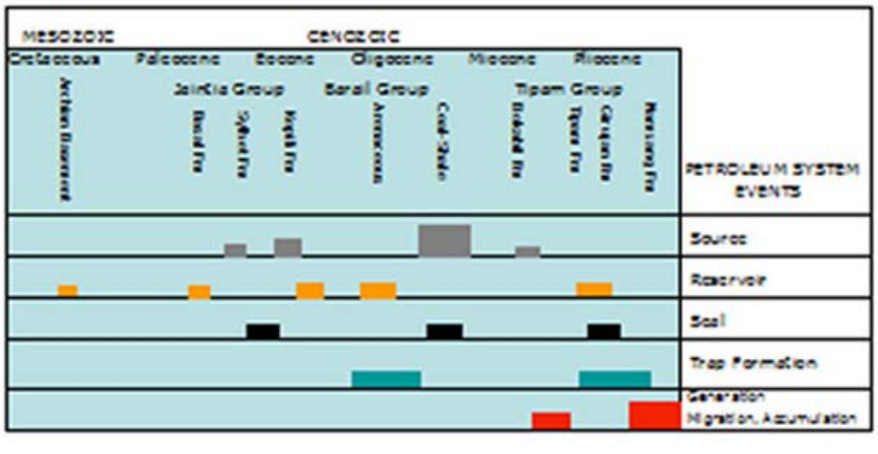


Fig. *A Comprehensive Petroleum System events of Assam basin*

Hydrocarbon Potential

The Brahmaputra Valley part of the Upper Assam Shelf south of latitude 27° 30', where active exploration for hydrocarbons has been continuing for about half a century, seems to have reached the middle stage of exploration maturity. But, the Dhansiri Valley shelf, areas north of Lat. 27° 30' and the Naga Schuppen belt are still in the early stage of exploration maturity. In the North Cachar area, exploration by deep drilling is yet to be initiated. Whatsoever, in view of what has been narrated on Upper Assam and Nagaland oil fields, and source, reservoir and cap rocks, and entrapment mechanism, the Brahmaputra valley still holds a large quantity of 'yet-to-find' oil, and Tinsukia – Sadiya area which partly falls in the Mishmi Depression; the Dhansiri valley and the Schuppen belt possess high hydrocarbon potential worth pursuing intensive exploration. The prognosticated resource base of the Upper Assam shelf and the Naga schuppen belt is roughly 3180 MMt, of which about 27% has been converted into inplace geological reserves. It is envisaged that the undiscovered oil would continue to be found in structural, strati- structural and subtle traps in areas mostly bordering the Naga thrust and in the Naga Schuppen belt.

Petroleum Plays :.

S.No.	Plays	Formation	Major Field
1	Mio-Pliocene	Girujan	Kharsang, Kumchai, Dirok
2	Miocene	Tipam	Hapjan, Digboi, Geleki, Charali
3	Oligocene	Barail	Naharkatiya,Lakwa, Lakhmani, Rudrasagar, Demulgaon, Sonari, Amguri, Hapjan, Shalmari,Kusijan, Laiplinggaon, Geleki
4	Mid-Upper Eocene	Kopili	Geleki
5	Lower Eocene	Lakadong+Therria	Dikom, Kathaloni, Baghjan, Panidihing, Tamulikhat, Tengakhat
6	Archean	Fractured Granatic Basement	Borhola, Champang